TH/5-3

Reduction of ELM energy loss by pellet injection for ELM pacing

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Introduction

Pellet injection is considered as one possible method to reduce ELM energy loss by increasing ELM frequency (ELM pacing).

ELM pacing by pellet requires,

(1) Significant reduction of ELM energy loss

(2) Small impact on plasma performance

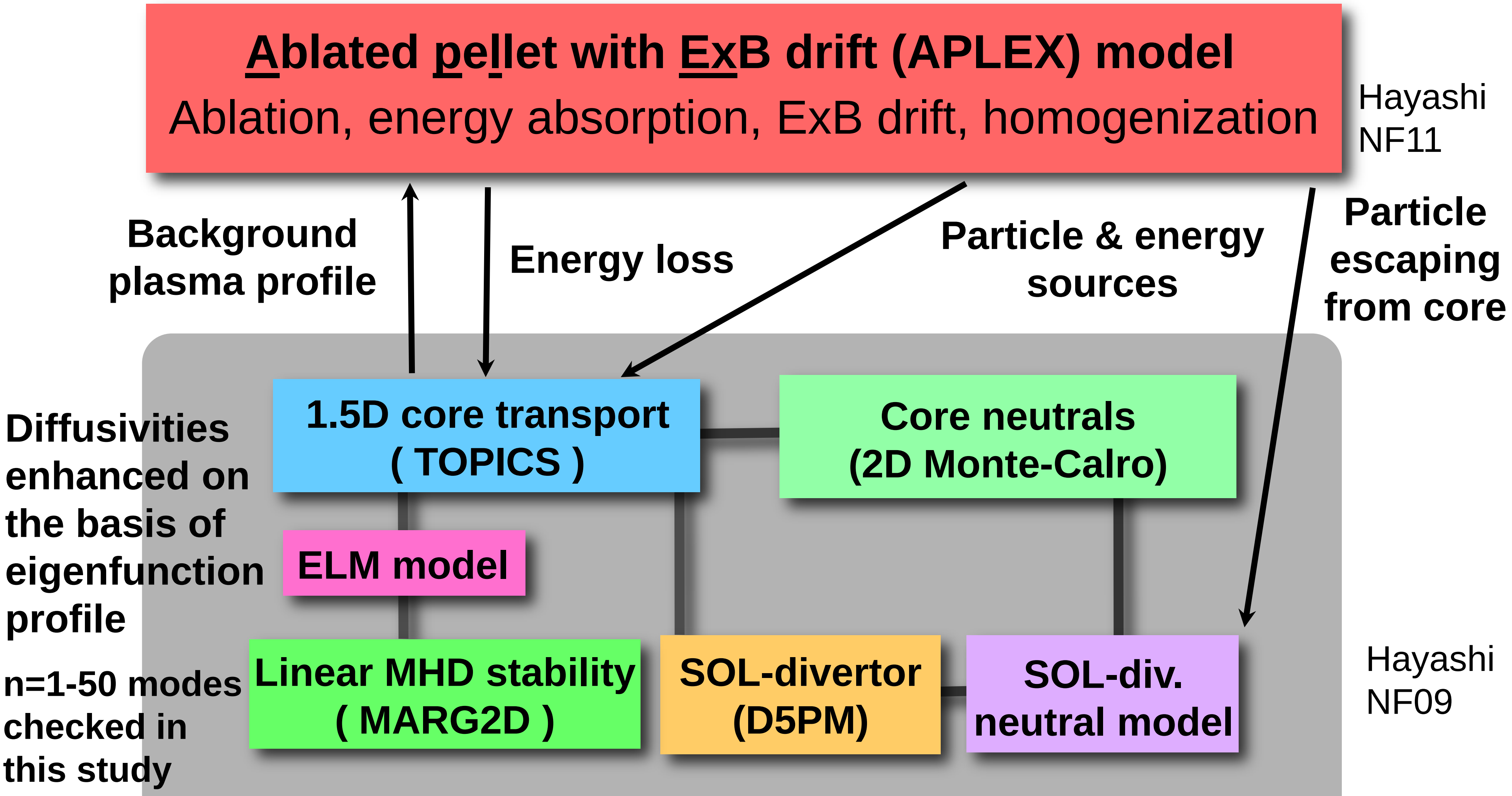
(3) Less particle fueling

Purpose of this paper

Integrated simulations by TOPICS-IB with various parameters
(pellet injection location, timing, size and speed)

- **Study reduction of ELM energy loss by pellet**
- **Examine suitable conditions of pellet injection for ELM pacing**

Pedestal modeling in TOPICS-IB



Ablated pellet with ExB drift (APLEX) model

Ablation, energy absorption, ExB drift, homogenization

Hayashi
NF11

Background plasma profile

Energy loss

Particle & energy sources

Particle escaping from core

1.5D core transport (TOPICS)

Core neutrals (2D Monte-Calro)

ELM model

Linear MHD stability (MARG2D)

SOL-divertor (D5PM)

SOL-div. neutral model

Diffusivities enhanced on the basis of eigenfunction profile

n=1-50 modes checked in this study

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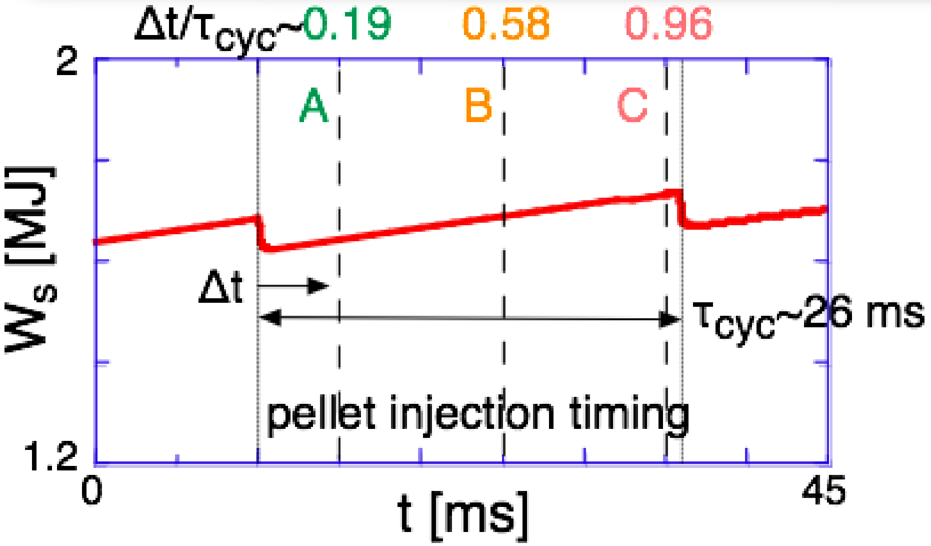
ELM version of TOPICS-IB could reproduce experimentally observed dependence of ELM energy loss on collisionality & pressure gradient inside pedestal top.

Integrated simulation results by TOPICS-IB

Reference natural ELMs for pellet injection

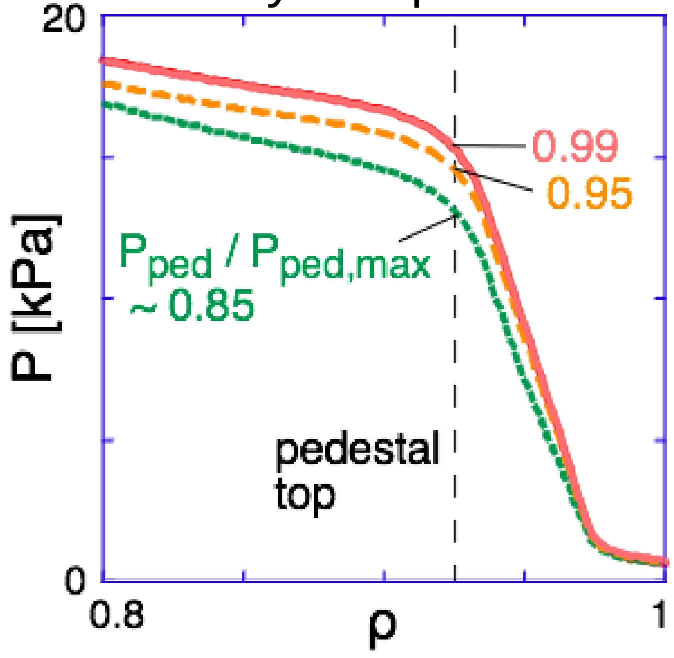


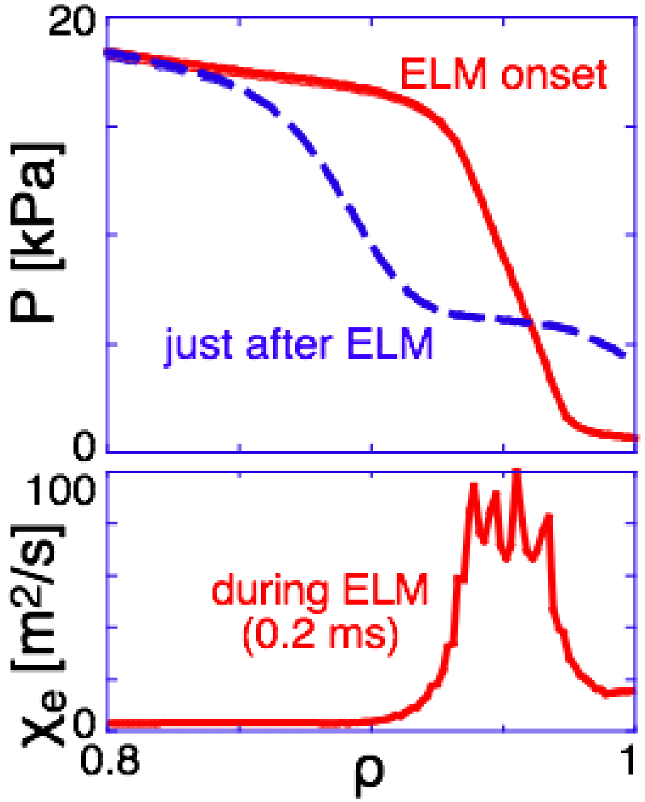
- Simulation with JT-60U parameters
- Pellet injectors: HFS & LFS
- 3 timings chosen for pellet injection

  A: early, B: middle, C: late

Prescribed anomalous diffusivity

Neoclassical diffusivity in given pedestal width





$\Delta W_{ELM} \sim 0.06$ MJ
$W_{ped} \sim 1$ MJ
$\Delta W_{ELM}/W_{ped} \sim 0.06$

Intermediate-n (n ~ 20) unstable

Diffusivity enhanced in whole pedestal

$$\chi_{ELM} \propto \xi_{r,n}^2$$

ELM triggering by pellet energy absorption

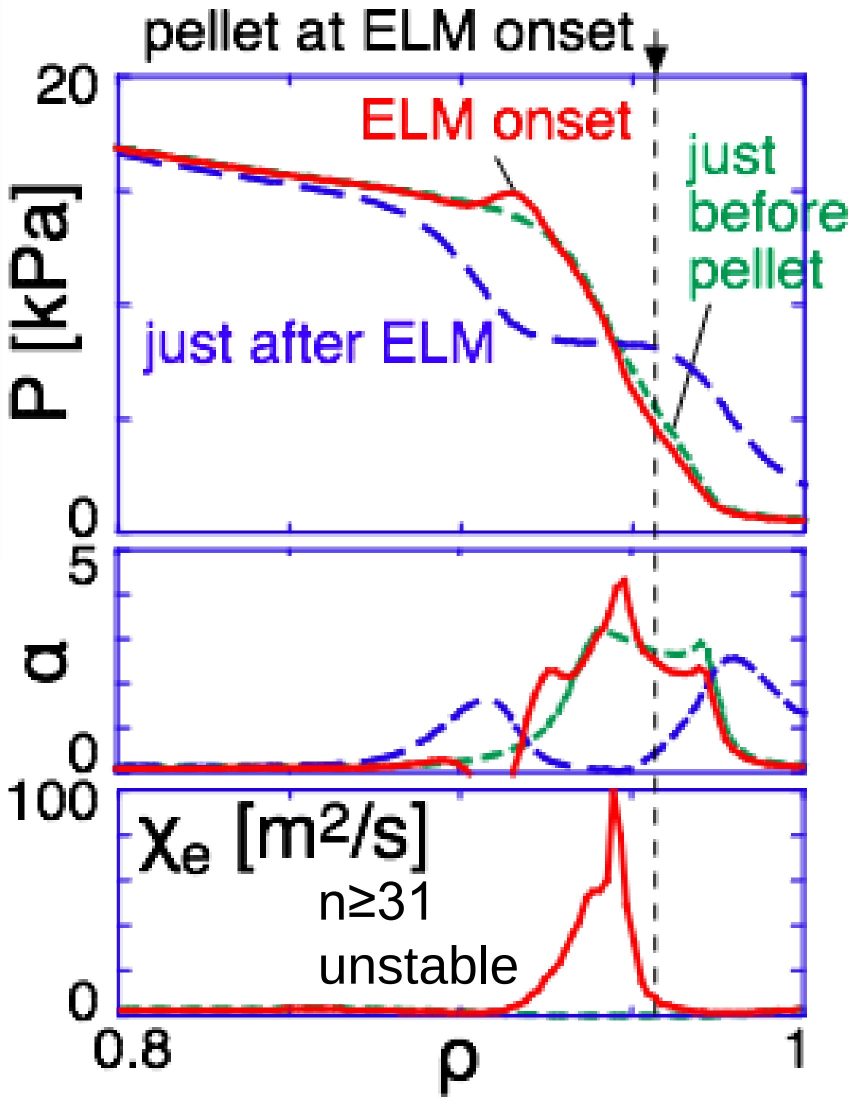
Mechanism:

(1) Pellet cloud absorbs background plasma energy. ExB drift shifts heated cloud inward for HFS pellet (or outward for LFS pellet) & deposits its energy in other region

(2) Modify background plasma profile & produce a local region with steeper pressure gradient, triggering an ELM

HFS injection at early timing A

Pellet size r_p=0.6mm, speed v_p=120m/s



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Right case: Narrow eigenfunction compared with natural ELM, leading to small loss

Mode number and eigenfunction depend on pellet injection location, timing, size and speed.

Dependence of ELM energy loss on pellet injection timing

Middle timing in natural ELM cycle is suitable to pellet injection for ELM pacing.

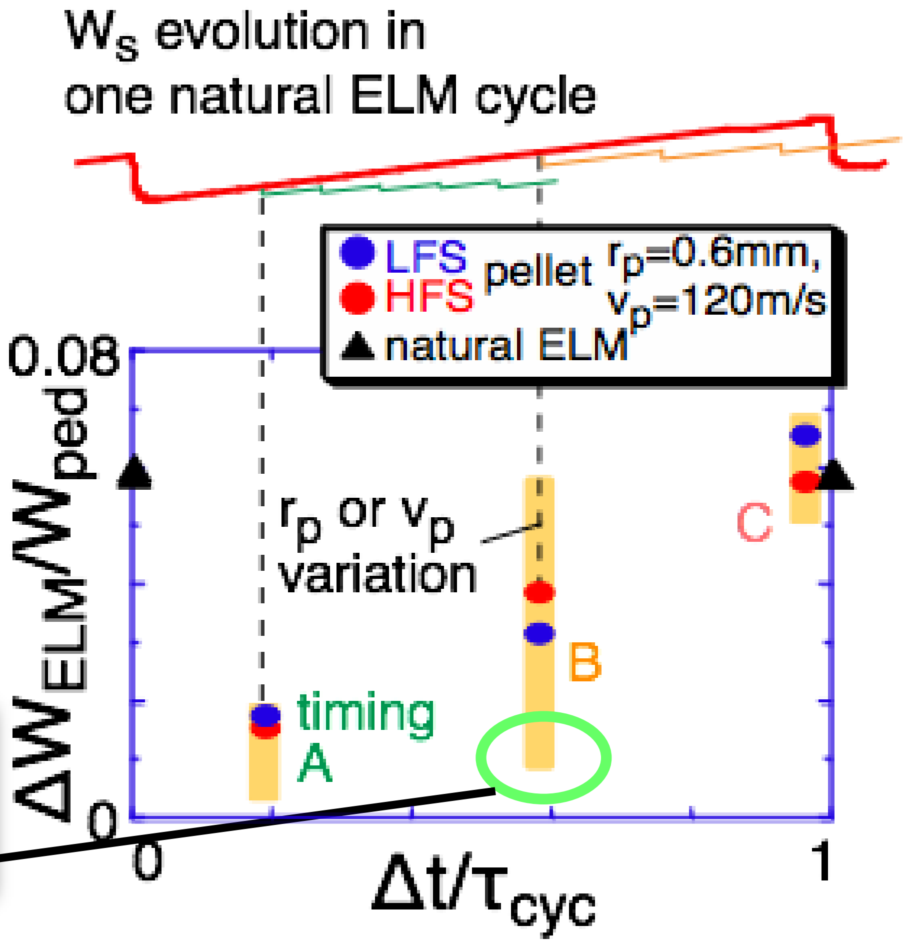
Late timing → Large energy loss (no merit)

Earlier timing → Smaller energy loss

- Higher-n modes with localized eigenfunctions near pedestal top
- Temporal decrease in BS current
  → magnetic shear increase
  → prevent lower-n modes
- BUT, **reduction of pedestal pressure**

Different size or speed
→ Small energy loss in middle timing

Energy loss vs elapsed time from previous natural ELM



Pellet size & speed dependence of ELM energy loss

Suitable conditions for ELM pacing by pellet

Injection timing in natural ELM cycle	early	[✓ middle]	late

Energy loss can be significantly reduced by LFS small pellet.

At middle timing,
Size variation with fixed speed

LFS smaller pellet → Smaller energy loss

HFS smaller pellet → Larger energy loss

ExB drift of pellet cloud produces

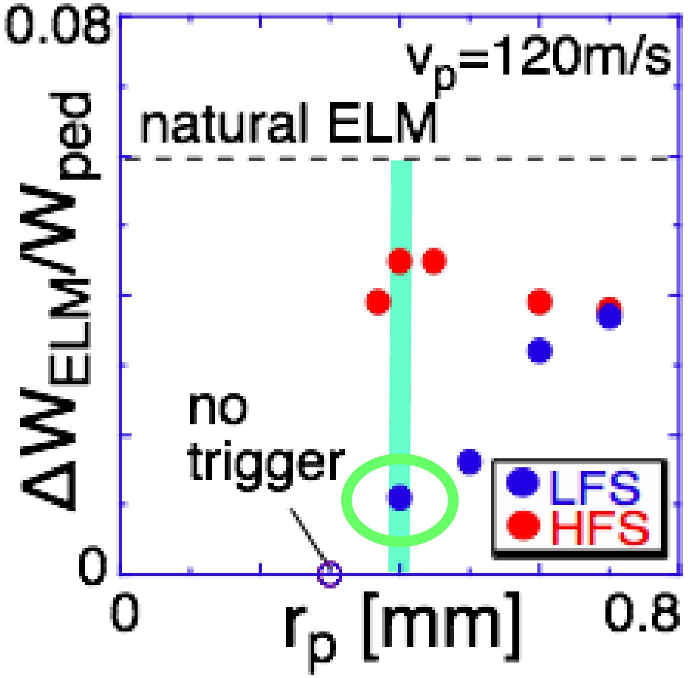
Narrow perturbation for LFS small pellet

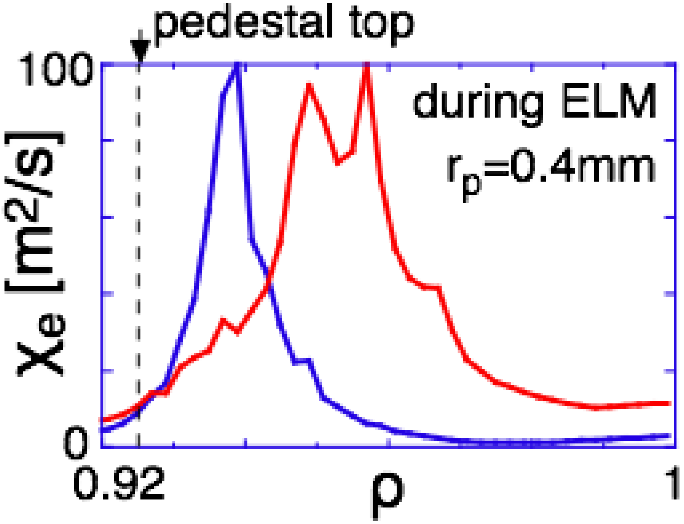
or

Wide perturbation for HFS small pellet

→ Difference of eigenfunction profile

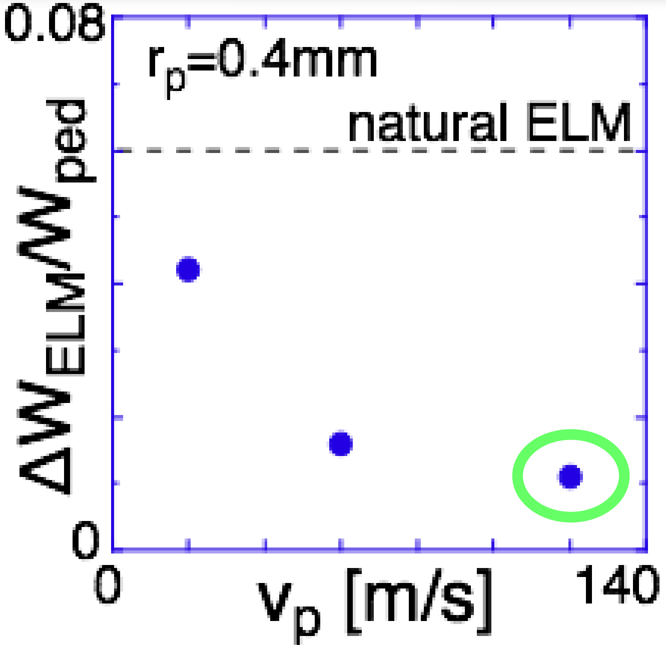
ELM energy loss vs pellet radius





Fast LHS pellet approaching pedestal top can significantly reduce ELM energy loss.

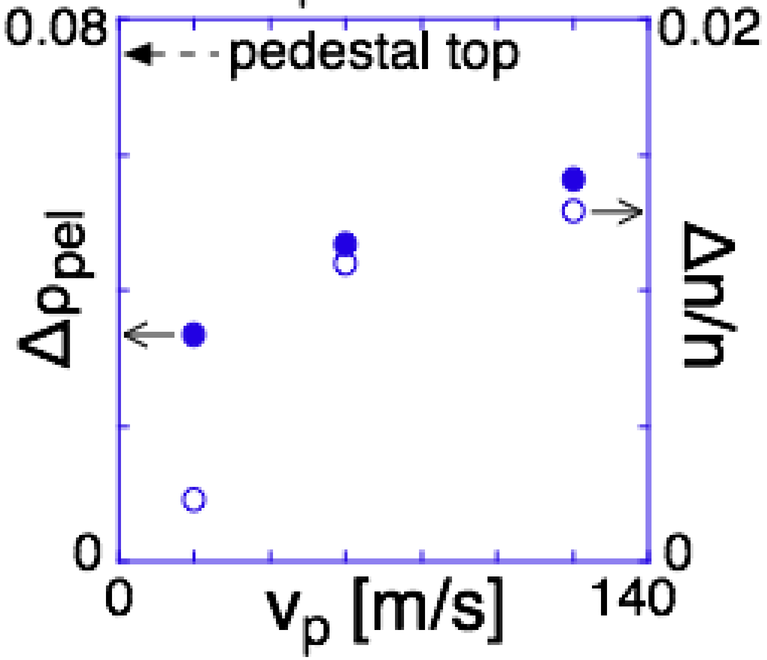
ELM energy loss vs pellet speed



With <u>LFS small pellet at middle timing</u>,
Speed variation with fixed size

Faster pellet → Smaller energy loss

Pellet ablation depth &
Core density increase



BUT, Faster pellet penetrating deeper into pedestal & Smaller ELM

→ Increase in core particle fueling

→ Only slight increase in core density, even for fast speed enough to approach pedestal top

Requirements for reduction of ELM energy loss

From simulation results with various parameters (pellet injection location, timing, size and speed)

Suitable conditions for ELM pacing by pellet

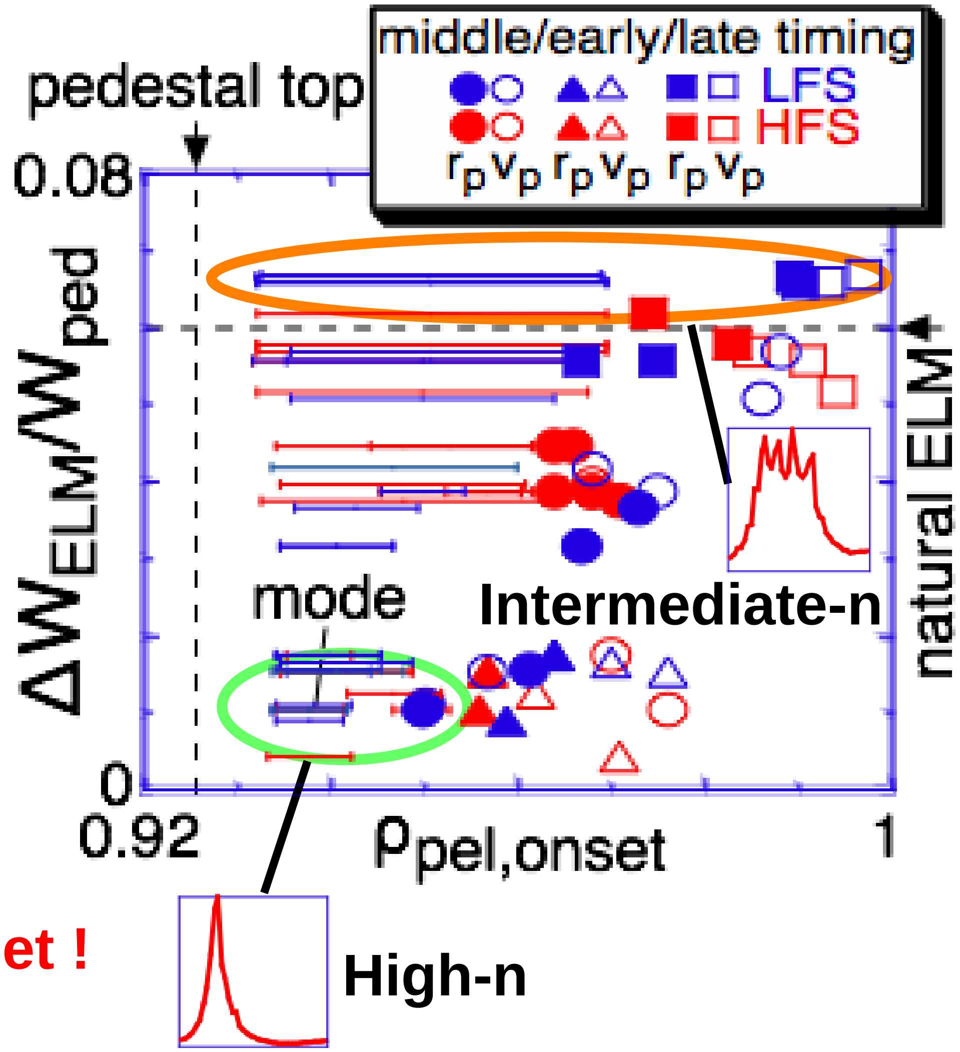
Injection timing in natural ELM cycle	early [✓ middle] late
Pellet injection location	[✓ LFS] HFS
Pellet speed	fast enough to approach pedestal top

ELM triggering by pellet at deep position results in significant reduction of ELM energy loss.

ELM energy loss & unstable mode location vs pellet position at ELM onset

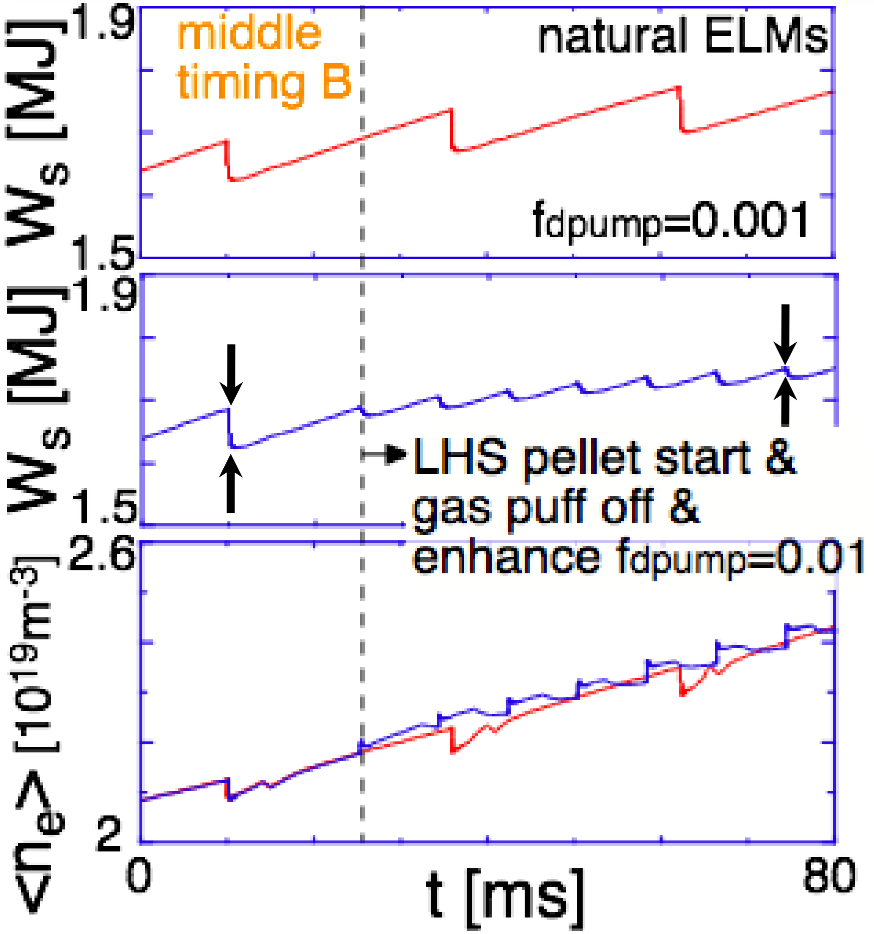
Triggering at deep position
→ Small energy loss
  High-n ballooning modes with localized eigenfunctions near pedestal top

Triggering at shallow position
→ Large energy loss
  Intermediate-n modes with wide eigenfunctions



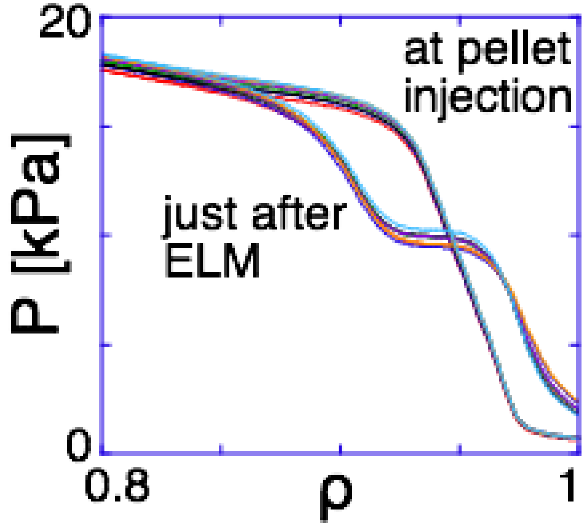
Repeat pellet !

Continuous pellet simulation with most suitable conditions



LHS pellet start &
gas puff off &
enhance fdpump=0.01

f_{dpump} : Pumping fraction of total particle flux to divertor plate



Collapse profile at each ELM triggered by pellet

ΔW_{ELM} reduction : 1/4.5

f_{ELM} increase : x 3.3

pellet particle fueling ~ gas puff

Core density increase due to particle fueling by pellet can be compensated by reducing gas puff and enhancing divertor pumping.

ELM frequency increase can be mitigated by pedestal neoclassical transport ($\propto n/T^{1/2}$) with transient density increase by pellet.

Conclusion

Integrated code TOPICS-IB predicts,

Small pellet significantly reduces ELM energy loss

By penetrating deeply into pedestal and triggering high-n modes with localized eigenfunctions near pedestal top,

With following conditions ;

Injection timing in natural ELM cycle (target $P_{ped}/P_{ped,max}$)	early (~ 85%	middle ~ 95%	late ~ 99%)
Pellet injection location	LFS	HFS	
Pellet speed	fast enough to approach pedestal top		

The above conditions lead to small impact on plasma performance & less particle fueling, and thus are suitable for ELM pacing by pellet.

Future works

- ITER simulation

Evaluate pellet size to reduce ELM energy loss
Study ELM pacing consistent with other particle fueling for the target density profile

- Model improvement

Pedestal model (time evolution of width)

- Sensitivity study

Simulations with other sets of parameters and the other triggering mechanism (pellet transport enhancement)

- Comparison with experiments and nonlinear MHD simulations

Trigger timing, energy loss, mode number etc.